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# Isospin dependence of the $\eta'$ meson production in nucleon–nucleon collisions

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**Abstract.** According to the quark model, the masses of $\eta$ and $\eta'$ mesons should be almost equal. However, the empirical values of these masses differ by more than the factor of two. Similarly, though the almost the same quark-antiquark content, the total cross section for the creation of these mesons close to the kinematical thresholds in the $pp \to ppX$ reaction differs significantly. Using the COSY-11 detection setup we intend to determine whether this difference will also be so significant in the case of the production of these mesons in the proton-neutron scattering. Additionally, the comparison of the $pp \to pp\eta'$ and $pn \to pn\eta'$ total cross sections will allow to learn about the production of the $\eta'$ meson in the channels of isospin I = 0 and I = 1 and to investigate aspects of the gluonium component of the $\eta'$ meson.

## INTRODUCTION

Despite the fact that the $\eta'$ meson was observed fourty years ago, its structure is still not known. According to the quark model, $\eta$ and $\eta'$ mesons can be described as the mixture of the singlet $(\eta_1 = \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} + s\bar{s}))$ and octet $(\eta_8 = \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s}))$ states of the SU(3) - flavour pseudoscalar meson nonet. Within the one mixing angle scheme, a small mixing angle $(\Theta = -15.5^0)$ implies that the masses of $\eta$ and $\eta'$ mesons should be almost equal. However, the empirical values of these masses differ by more than the factor of two, and the mass of the $\eta'$ does not fit utterly to the SU(3) scheme.
More surprisingly the masses of all pseudoscalar mesons, vector mesons and baryons are well described in terms of naive quark model.
At present there is also not much known about the relative contribution of the possible reaction mechanisms of the production of the $\eta'$ meson. It is expected that the $\eta'$ meson can be produced through heavy meson exchange, through the excitation of an intermediate resonance or via emission from the virtual meson [11].

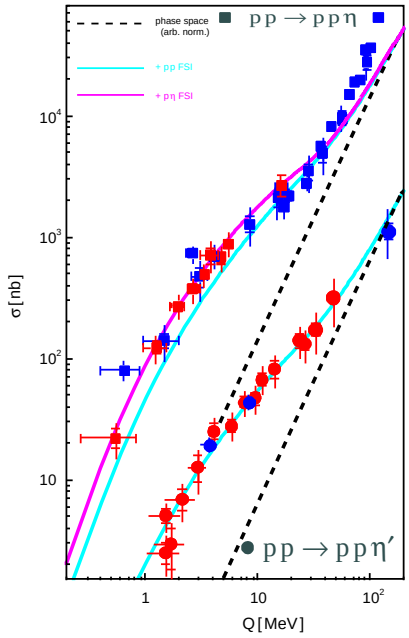


**FIGURE 1.** Total cross section for the reactions $pp \to pp\eta'$ (circles) and $pp \to pp\eta$ (squares)as a function of the centre–of–mass excess energy Q. Data are from references [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]

However it is not possible to judge about the mechanism responsible for the $\eta'$ meson production only from the total cross section of the $pp \to pp\eta'$ reaction. Therefore one has to investigate the $\eta'$ production in proton-neutron scattering in order to impose the additional constraint on the existing theoretical models. Moreover, there is also one significant aspect of these studies, viz the close–to–threshold production of $\eta'$ meson in the nucleon–nucleon collisions requires a large momentum transfer between nucleons and occurs at distances in the order of 0.3 fm and this implies that the quark–gluon degrees of freedom may play a significant role in the production dynamics of this meson. Therefore it is possible that the $\eta'$ meson is created from excited glue in the interaction region of the colliding nucleons [12, 13, 14]. It is interesting to note that recently Bass and Thomas [15] argued that the strength of the interaction of $\eta$ and $\eta'$ mesons with nucleons is sensitive to the singlet-flavour component, and hence to the glue in these mesons. This makes a connection in our endeavour to investigate the structure, the production dynamics, and the interaction of the $\eta$ and $\eta'$ mesons with nucleons.

## ISOSPIN DEGREES OF FREEDOM

Treating proton and neutron as different states of nucleon distinguished only by the isospin projection, $+\frac{1}{2}$ for the proton and $-\frac{1}{2}$ for the neutron, we may classify the $NN \to NNX$ reactions according to the total isospin of the nucleon pair in the initial and final state. A total isospin of two nucleons equals 1 for proton–proton and neutron–neutron pairs, and may acquire the value 1 or 0 for the neutron–proton system. Since

$\eta'$ meson is isoscalar, there are only two pertinent transitions for the $NN \to NNX$ reaction, provided that it occurs via the isospin conserving interaction. It is enough to measure two reaction channels for an unambiguous determination of isospin 0 and 1 cross section [16].
As discussed in references [12, 13, 14] the comparison of the $pp \to pp\eta'$ and $pn \to pn\eta'$ total cross sections will allow not only to learn about the production of the $\eta'$ meson in the channels of isospin I = 0 and I = 1 but also to investigate aspects of the gluonium component of the $\eta'$ meson.
Such investigations were already performed in case of $\eta$ meson, and the total cross section in both the proton–proton as well as the proton–neutron reactions has been measured. The ratio $R_\eta = \frac{\sigma(pn\to pn\eta)}{\sigma(pp\to pp\eta)}$ was determined to be about 6.5 [17] in the excess energy range between 16 MeV and 109 MeV. Since,

$$\sigma(pp \to pp\eta) = \sigma_{I=1},$$

$$\sigma(pn \to pn\eta) = \frac{\sigma_{I=0} + \sigma_{I=1}}{2}$$

we have

$$\sigma_{I=0} = (2R_\eta - 1)\sigma_{I=1},$$

where I denotes the total isospin in the initial and final state of the nucleon pair. This means that the production of $\eta$ meson with the total isospin I=0 exceeds the production with the isospin I=1 by a factor of 12. This large difference of the total cross sections suggests the dominance of isovector mesons exchange in the creaction of $\eta$ in collisions of nucleons.
Since the quark structure of $\eta$ and $\eta'$ mesons is very similar, in case of the dominant isovector meson exchange – by the analogy to the $\eta$ meson production – we can expect that the ratio $R_{\eta'}$ should be about 6.5. If however $\eta'$ meson is produced via its flavour-blind gluonium component from the colour-singlet glue excited in the interaction region the ratio should approach unity after corrections for the initial and final state interactions [12].

## STATUS OF THE EXPERIMENT

The close–to–threshold excitation function for the $pp \to pp\eta'$ reaction (see fig.1) has been already determined, whereas the total cross section for the $\eta'$ meson production in proton-neutron interaction is still unknown. Therefore we have performed the measurement of the quasi–free $pn \to pnX$ processes using a proton beam and a deuteron cluster target. In two separated runs we have measured the $pn \to pnX$ process close to the $\eta$ and $\eta'$ production threshold. For the preliminary results on the $pn \to pn\eta$ process the interested reader is referred to reference [18]. The experiment is based on the registration of all outgoing nucleons from the $pd \to p_{sp}pnX$ reaction. Protons are measured in two drift chambers and scintillator detectors [19, 20], neutrons are registered in the neutral particle detector [21, 22]. Protons considered as a spectators are measured by the dedicated silicon-pad detector [23, 24]. Application of the missing mass technique

allows to identify events with the creation of the meson under investigation and the total energy available for the quasi-free proton-neutron reaction can be calculated for each event from the vector of the momentum of the spectator proton. For more detailed description of the experimental method see references [25, 26, 27].
At present the analysis aiming for establishing the excitation function for the $pn \to pn\eta'$ reaction is in progress and will deliver the values for the total cross section in the excess energy range between 0 and 20 MeV.

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